

Constraints as Means of Controlling Usage of Geovirtual Environments

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ABSTRACT: In this paper a concept for controlling the usage of geovirtual environments by means of constraints is developed. Constraints serve to improve the usability of geovirtual environments by guarding the navigation and interaction processes of users. In addition, they facilitate the implementation of Digital Rights Management for geovirtual environments. The presented approach distinguishes spatial constraints, structural constraints, and redistribution constraints. Several types of spatial constraints have been identified for navigation in geovirtual environments. To demonstrate their applications, this paper reports on using constraints in virtual 3D city models.

KEYWORDS: Geovirtual environments, geovisualization, 3D maps, 3D city models, navigation, user guidance, usability, constraints

Introduction

Distributing geovisualization systems, applications, and documents raises the question of how an author can control the way a potential user is presenting, exploring, analyzing, modifying, and redistributing contained geoinformation. The concept of constraints as means of controlling usage of geovirtual environments provides means for Digital Rights Management (DRM) and improves user guidance and usability.

This contribution is focusing on interactive 3D geovisualization systems and applications such as for 3D maps, 3D city models, and 3D landscapes (Figure 1). In the following we refer to these systems and applications as *geovirtual environments* (GeoVEs). The GeoVEs systems and applications typically process large raster and vector geodata sets, rely on real-time 3D rendering, and provide application-specific interaction functionality, such as support for interactive planning, analysis, exploration, or editing of geodata and geobjects.

Controlling usage becomes more and more important because GeoVEs emerge as parts of an increasing number of applications, systems, and products containing geodata as one of their major data category. Consider for example administrations that want to deliver geodata to citizens within a public participation process, an e-commerce company trading geodata that wants

to deliver requested geoinformation to their customers, or built-in geo-databases such as for 3D car navigation systems. In all cases, the content providers need to ensure the effective usage and controlled redistribution of geodata accessible and provided by GeoVEs.

Digital Rights Management for Geovirtual Environments

Constraints provide a basis for Digital Rights Management (DRM) in GeoVEs. Digital Rights Management “involves a collection of hardware, software, services, and technologies for persistently governing authorized distribution and use of content and services according to their associated rights” (Wang 2004). Its original focus was on models of dissemination and use of intellectual property assets. However, because of DRM’s impact on industry and business models, the technology is increasingly being used to define techniques and mechanisms for identifying, describing, packaging, distributing, and controlling the use of digital contents. For the general characteristics of DRM systems see Koenen et al. (2004).

The DRM technology becomes necessary when legal aspects such as copyright or license issues are relevant and need to be fulfilled by authors. For example, a geodata trading company which collects, composes, and refines geodata most likely has to follow different contractual obligations for each geodata source. An effective and efficient solution would be for the company to deliver composed, refined geodata by means of 3D

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maps that are restricted in their usage according to the contractual situation. As long as GeoVEs and their constituent geodata are used, distributed, and modified within a trusted and known context, protection and controlling issues of the data and their visualizations can be ignored, but once geodata and GeoVEs are targeted in an open context, these issues appear to be critical due to technical, legal, and strategic implications.

The Open Geospatial Consortium (OGC 2004) has recently noted that the “lack of a geospatial Digital Rights Management (GeoDRM) capability is a major barrier to broader adoption of Web-based geospatial technologies.” Many general-purpose approaches of DRM appear to be non-optimal. For example, the MPEG-21 rights expression language (Wang 2004), a machine-interpretable language developed to specify rights unambiguously with a corresponding authorization model, provides solutions for multimedia contents. However, MPEG-21 does not provide explicit support for the presentation, exploration, analysis, and editing of geoinformation. Hence, it became necessary to identify DRM approaches specific to the nature and usage of geoinformation. The proposed constraint objects represent one approach towards GeoDRM.

Improving Usability of Geovirtual Environments

Controlling the usage of GeoVEs can also serve to improve usability from the users’ perspective; they benefit from system-assisted and system-guided interaction strategies to cope with the large number of degrees of freedom inherent in 3D visualization.

To improve usability of 3D interaction processes, we have to assist users to navigate through, and interact with, the three-dimensional world and its objects. As Burtnyk et al. (2002) point out, common problems of users of interactive 3D applications include “a user may «get lost» in the scene, view the model from awkward angles [...], miss seeing important features, experience frustration at controlling their navigation, etc.” Fuhrmann and MacEachren (2001) observed similar phenomena with regard to GeoVEs, and, saw the necessity to “design more productive geovisualization applications, where users spend their time exploring data relationships or making decisions rather than trying to figure out where they are.” As a result, they proposed, for example, new metaphors such as the general flying vehicle.

Adaptive, context-aware techniques for user navigation and user interaction provide a solution to the issue of usability in GeoVEs. As an example of a context-aware navigation, consider GeoVEs which contain no valid geodata in specific areas. To prevent users from going to those areas and misinterpreting what is there, an appropriate constraint could be designed to take over the control of the movement of the virtual camera to bypass those areas.

Constraints

Constraints have the main objective to adjust the degrees of freedom of usage and redistribution by restricting and controlling constituent components of GeoVEs. Technically, constraints can be modeled as components of GeoVEs. These components are constructed and managed similar to geometry, appearance, interaction, or animation building blocks.

Three different groups of constraint types are:

- *Spatial constraints*—These constraints restrict spatial parameters of GeoVEs such as camera position, orientation, and movement;
- *Structural constraints*—These constraints restrict operations that modify GeoVE components, such as replacing or adding components;
- *Redistribution constraints*—These constraints define the properties of redistributed GeoVEs.

The contents of GeoVEs can be specified using such graphics middleware as:

- Scene description languages, for example VRML (Virtual Reality Modeling Language), its geo-specific extension GeoVRML, and X3D (an XML-based successor to VRML);
- Scene-graph APIs such as OpenSceneGraph, OpenInventor, Virtual Rendering System (VRS), and Java3D;
- Geo-specific visualization systems such as GeoVISTA.

To this day, however, graphics middleware does not offer constraint technology as integral functionality.

The examples described in this paper are based on LandXplorer (3D Geo 2004a), a 3D geovisualization authoring system which provides a set of general-purpose components for composing 3D maps, 3D city models, and 3D landscape models. This system constructs GeoVEs in an object-oriented manner represented as hierarchically organized documents, which consist of various content components such

as digital terrain models, terrain texture layers for raster geodata and vector geodata, and 3D objects. The system also provides interaction and animation components such as 3D analysis tools for measurements, data exploration tools, and camera paths and viewpoint management tools. Döllner and Kersting (2000) give an overview of the LandXplorer's system architecture.

The constraints concept does not assume a specific rendering engine or framework; consequently, the implementation can be ported to any scene-graph API. Such an implementation would be complementary to the implementation of typical geovisualization components.

Spatial Constraints

Controlling the way users can navigate through a GeoVE implies the control of GeoVE usage since the user relies on navigation and orientation as "primary functions for GeoVEs, functions that support all other interactions necessary to analyze geospatial data and understand geographic phenomena" (Fuhrmann and MacEachren 1999). Therefore, one effective way for controlling usage consists in defining constrained navigation techniques.

Navigation Techniques

Navigation techniques in GeoVEs need to take into account their characteristics to achieve high usability compared to standard navigation techniques found in general 3D environments. That is, navigation techniques should adhere to the characteristics of the represented data and the tasks supported by GeoVEs. In particular, navigation techniques should take into account:

- Varying scales: Users may vary between local-scale views (e.g., virtual avatar in 3D city model) and global-scale views (e.g., flying helicopter above the city and its surroundings) to complete their tasks in GeoVEs;
- Outdoor situations: Emphasis is on visualizing outdoor situations, that is, spaces, rather than indoor situations; and
- Geodata contents: Emphasis is on visualizing georeferenced data, typically projected on top of the terrain surface or represented as objects on top of the terrain surface, i.e., geodata are the central category of contents in GeoVEs.

There are numerous navigation techniques for virtual environments and GeoVEs. They can be classified into egocentric and exocentric frame-

of-reference (Hand 1997) and distinguished according to the task they are suited for (Tan et al. 2001). The most important navigation techniques include:

- *Pedestrian navigation*: The user explores a virtual environment from the point of view of a virtual avatar which can walk in four directions and rotate its gaze around two axes using a mouse. This technique has become quite popular due to its frequent use in computer games.
- *Flyer navigation*: The user controls a virtual flying vehicle. He or she manipulates the speed of the forward/backward movement and the rotation around the world's up-vector. In addition, the flying vehicle allows users to change the height or to tilt the view direction. The Flyer technique is frequently used in geovirtual environments.
- *Click-&-Fly navigation*: The user indicates a visual target, and the system calculates a camera flight that brings the viewer on the trip towards the target (Mackinlay et al. 1990).
- *Landmark navigation*. The user selects pre-defined landmarks, and the system calculates on-demand camera paths from the current position to the pre-defined viewpoint (Helbing and Strothotte 2000; Salomon et al. 2003).
- *Trackball navigation*. The user moves the camera positioned on the surface of a virtual sphere.
- *Zoom navigation*. This controls the distance of the camera to a focus point, thereby increasing/decreasing the visible area inside the view plane.
- *Focus navigation*. The user switches from the current focus point, located in the middle of the view plane, to a new 3D location of the virtual environment. If the user selects a new point, the camera rotates to move the selected point to the center of the view plane. This navigation technique was developed to support point-anchored exploration functionality in GeoVEs (Döllner & Kersting, 2000).

For local-scale inspection and analysis, Trackball, Zoom, and Focus navigations are preferable; for global-scale exploration Pedestrian, Flyer, and Click-&-Fly navigations are frequently used. If targets are known in advance, Click-&-Fly and Landmark navigations appear to be adequate. It has been observed that users interacting with GeoVEs may need to switch frequently between different tasks,

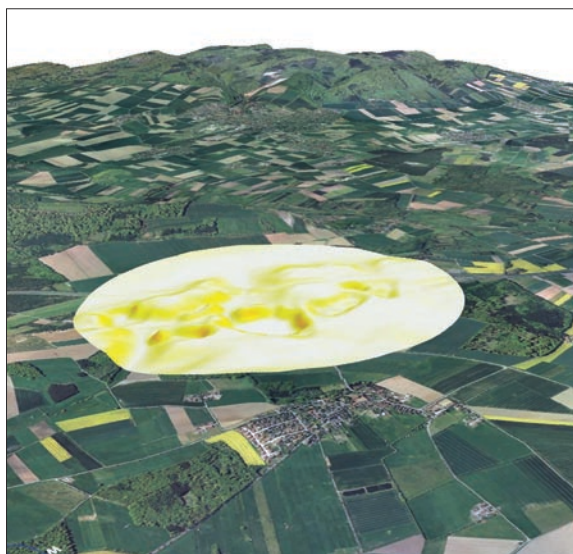


Figure 1. Examples of specialized geovirtual environments: Figure 1a) 3D map with aerial photography and a superimposed information lens visualizing the slope degree (Image: HPI).

different scales, and, hence, different navigation techniques. Therefore, different navigation techniques should operate in sync, and users should be able to switch between them seamlessly.

Guided Navigation

Guided navigation has been applied successfully to support user orientation and user experience and to create the user's cognitive map. According to Galyean's (1995) river analogy, "the user is guided by a predefined path and controls the gaze direction along with slight deviations away from the path." Hanson and Wernert (1997) propose that, "rather than controlling an unconstrained vehicle in 3D space, the 2D control device is actually moving the user on a constrained subspace, the »guide manifold«, a kind of virtual 2D sidewalk." That is, using 2D input devices, the user moves on a designer-provided (invisible) two-dimensional surface. The remaining degrees of freedom are controlled by pre-defined guide fields according to the camera position. This method has been extended and applied to collaborative virtual environments (Wernet and Hanson 1999). According to Hughes and Lewis (2002), the attentive camera addresses the problem of guiding the view direction without distracting the user from the intended walk direction. Kiss and Nijhold (2003) presented a system that alters the view direction based on the terrain slope



Figure 1b) 3D landscape model visualizing the lost Italian gardens of Park Sanssouci, Potsdam (Image: Lenne3D).



Figure 1c) Snapshot from the 3D city model of Berlin, Germany (Image: 3D Geo).

and some objects of interest around the camera position. Each object of interest is suggested to the user by shortly focusing it. The system also ensures that the user is always aware of obstacles that prevent the user from moving. Burtnyk et al. (2002) present a semi-automated camera control system based on pre-defined viewing zones and camera animations between them—a strong and effective form of guided navigation that "allows for a satisfying level of interactivity while avoiding the problems inherent in using unconstrained camera models."

The constraints proposed in this paper are independent of the individual navigation technique; their functionality can be integrated in the implementation of a technique or, in a broader sense, they can be part of post-processing applied after new camera settings have been calculated. This

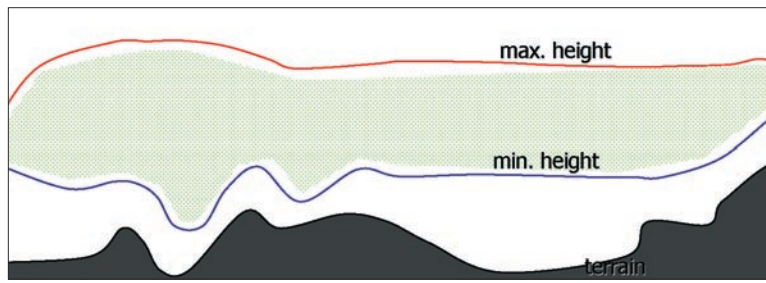


Figure 2. Cross-section illustrating the minimal-height field and the maximal-height field. The space in-between represents the valid space for positioning flying vehicles. The minimal-height field follows generally the terrain surface. The maximal-height field typically has a constant setting except for areas where more overview should be possible.

way, classical and well known navigation techniques can incorporate a system-assisting behavior.

Guided navigation can be implemented using the following spatial constraints:

- *Terrain distance constraint*—Controls a camera's heights.
- *Camera-orientation constraint*—Controls and corrects a camera's look-to direction.
- *Camera-position constraint*—Controls a camera's look-from point.
- *Distance-texture constraint*—Controls visibility and appearance of visualized data.

Navigation constraints cannot interfere with the interaction process between user and a GeoVE if they are to be accepted in the long run. They need to demonstrate a comprehensive behavior that convinces users that it can help them to be more effective, while meeting the imposed restrictions.

Navigation controls can behave comprehensively by applying:

- *View adjustment strategy*, which corrects and transforms camera settings when navigation models are switched; or
- *Orientation measurement strategy*, which attempts to maintain a high orientation value during navigation.

Terrain-Distance Constraint

As a basic spatial constraint, the terrain-distance constraint controls the distance between the virtual terrain model and the virtual camera by using a defined minimum-height field and a maximum-height field (Figure 2). Both fields are two-dimensional grids, whose values denote heights;

their resolution is independent from the resolution of the digital terrain model.

The minimum-height field provides a kind of collision detection with the terrain surface and the objects on top of it. Initially, the field can be set to a fixed height above ground for the whole extension. It can then be refined if 3D building objects (e.g., a 3D city model) and 3D vegetation objects (e.g., average heights by land use) are included. The minimum-height field can also be used to allow the camera to be closer in areas of high-data quality,

while keeping it at a greater distance in areas with no data or with data of lesser quality.

The maximum-height surface defines the extent of overview a user is allowed to obtain. Initially, this field can be set to a fixed value above the ground. Towards the borders of the virtual environment, the maximum heights can be reduced to pull down the camera once it approaches the border.

Camera-Orientation Constraint

This constraint has the ability to limit the viewing direction of a virtual camera. During interactions awkward viewing directions are responsible for many usability problems, in particular when users do not respond quickly enough to reverse the flight direction. One application of this constraint is to prevent that the camera looks towards the sky (Figure 3) by restricting the allowed angle range. However, since the user can see at least part of the virtual terrain with this constraint applied, he or

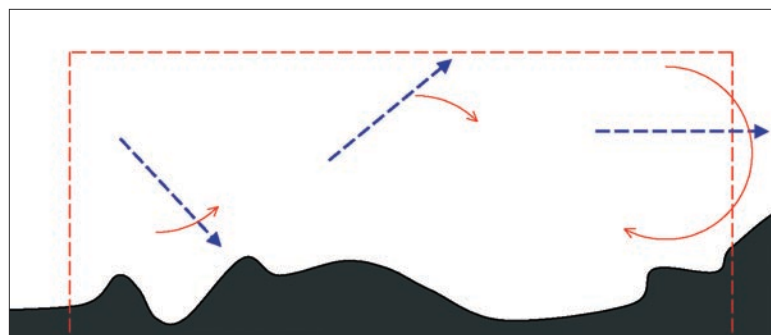


Figure 3. Example of view-orientation constraint strategies. The (blue) dashed arrows indicate the current movement direction, the red arrows indicate in which direction the camera-orientation constraint will redirect the movement direction in order to prevent collision (left), views completely towards the sky (middle), and views to the outside area (right).

she will not become disoriented while navigating through the environment. Another application is in geodata protection and it involves constraining the viewing direction in such a way that at no time a strictly orthogonal view is achieved. Whenever this view is attempted, the camera tips over to the side. Thus, while the user may explore the aerial photography, no strictly orthogonal views can be captured.

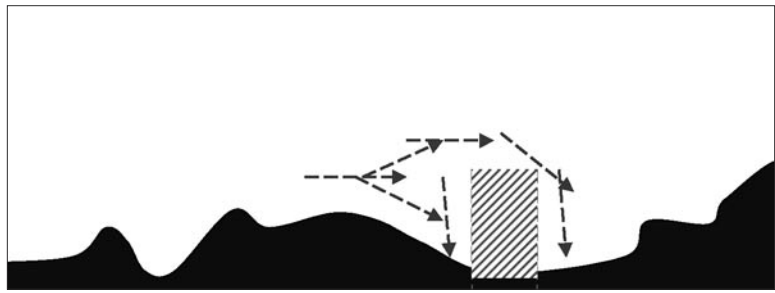


Figure 4. Example of camera-position constraint strategies. User are not allowed for passing through the no-go area, indicated by the dashed block. The constraint needs to redirect the movement direction either towards the front or over the no-go area (dashed arrows).

Camera-Position Constraint

The camera-position constraint defines where the virtual camera can be placed and where virtual viewers are allowed to stand and pass by. Applied within pedestrian navigation, this constraint defines virtual “no-go areas” (Figure 4). If the user directs the virtual avatar into a no-go area, the avatar cannot proceed and must return. This way one can prevent users from entering, for example, areas of 3D city models that have not yet been modeled.

The camera position constraint also checks for collisions with all the geometric objects of geovirtual environments, including such hidden auxiliary objects as invisible walls. This complementary function of the constraint blocks access to specific areas. The invisible objects should be outlined once the virtual avatar comes close to them, thus revealing the existence and behavior of the constraint to the user.

Orientation Measurement

Each spatial constraint defines a strategy to hold the orientation value at a sufficiently high level, assuming that the previous view already had a high orientation value. This strategy checks the view specification proposed by the active navigation technique. If the resulting orientation value falls below a certain threshold value indicating that the user is approaching a disorienting situation, the orientation constraint corrects the view specification. As long as enough orientation-supporting information is provided, the user can transit also through regions of lower interest. As a general functionality, the maintenance strategy checks for collisions of the virtual camera with the environment.

The simplest method to keep a high orientation value is to block the proposed movement by

using the previous view specification. Blocking the movement, however, usually leads to disturbing effects. An improved method identifies the user's intention and guides the user away from disorienting views, based on the intention and outweighing the degraded orientation with corrections in orthogonal movement degrees. Figure 5 illustrates the maintenance strategy of the Flyer navigation technique in the context of terrain visualization. The three typical instances where the user is about to navigate into a critical situation are:

- The user rotates the flight direction and causes the camera to look too far beyond the terrain border. The rotation is accepted but outweighed by a slight rear movement away from the border.
- The user is flying forward beyond the terrain border. The maintenance strategy temporarily tilts down the view direction, if this is possible.
- If no more tilting is possible, the strategy rotates the flight direction parallel to the terrain to fly along the terrain border.

View Adjustment

The adjustment strategy ensures that the active navigation technique is capable of processing the current view specification. While a navigation technique is active, its orientation constraint never produces view specifications that cannot be handled by the technique. After a switch between navigation techniques, however, the newly active navigation technique is confronted with arbitrary view specifications. The orientation adjustment strategy calculates a close applicable view specification if the current one is not usable for the active technique.

Figure 6 illustrates an orientation adjustment strategy for the focus navigation technique. After a switch from the pedestrian technique, no focus

point is defined. Since the focus technique needs a valid destination to zoom to, the adjustment strategy tilts the view direction until a focus point is hit. During this animation, however, the user will not lose control. The user can interrupt the animation at any time by using a different navigation technique.

Distance-Texture Constraint

Like the navigation constraint, the distance-texture constraint is a spatial constraint, but it differs in that it activates, and blends in, a special terrain texture on top of all other terrain textures according to the distance of a point on the terrain surface and the virtual camera. To configure a distance-texture constraint, we specify the blend-in texture, the minimal and maximal distance at which the blending process starts and ends, and visual weights for both distances, which are used to calculate the actual transparency value.

One possible application of this constraint is in watermark texture containing the image of a copyright statement. If the user comes close and is able to see more details, the watermark appears. Using a distance-texture constraint, GeoVEs can view terrain textures unmodified by close views, thus preventing the capture of the visible geodata. Figure 7 exemplifies these concepts.

Structural Constraints

Structural constraints define in which way users can redefine the structure and contents of the distributed GeoVEs. They allow authors to define where and what users can modify, that is, they define how GeoVEs can be personalized and configured once they are distributed. These constraints are different to spatial constraints because they do not directly intervene with the interaction between the user and the GeoVE.

Examples of structural constraints include:

- *Add-Object constraint*—Controls whether new graphics or behavioral objects can be inserted into given GeoVEs. If applied to the root node of a GeoVE scene specification, the GeoVE cannot be extended or personalized by users. Most important, this constraint defines whether new geodata can be included into an existing GeoVE. For example, a user may want to extend a given GeoVE by additional terrain information layers and, therefore, wants to include a new terrain texture;
- *Remove-Object constraints*—Controls whether existing objects of a GeoVE can be removed or decomposed. If applied to the root node of a GeoVE scene specification together with a blocking add-constraint, a GeoVE becomes a “use-only” system. This constraint defines the permission to enable and disable contained presentation, structure, interaction, and animation objects of a GeoVE. For example, a user may want to switch off a given terrain texture or to hide annotations.
- *Property-Change constraint*—Controls property changes of contained graphics and behavioral objects. For example, authors may want to allow colors in legends to be changed but not the texts of labels.

Structural constraints can be restricted to objects of specific presentation, interaction, and animation classes. For example, users may be allowed to add label objects to personalize their GeoVE, but they may not be allowed to add new terrain textures.

Redistribution Constraints

Redistribution constraints define in which way users can derive distributable GeoVEs from a given GeoVE. Examples of redistribution constraints include:

- *Export constraint*: This constraint defines the permission to explicitly save objects contained in GeoVE. “Export” refers to the ability of contained geodata objects to be exported in their original data formats. For example, if the digital terrain model can be exported, the original terrain representation, at full resolution, can be extracted (in contrast to its multi-resolution model). It also refers to the ability of a whole geovisualization document to be saved after modifications have been made.
- *Watermark constraints*: Both visible watermarks (e.g., logos) and non-visible watermarks (e.g., encoded in the digital terrain model) can be enforced, i.e., derived GeoVEs cannot exclude these elements (and may not even be aware of them).
- *Editing constraints*. These constraints define the permission to edit GeoVEs by the authoring system. If GeoVEs are distributed, this core permission determines, whether a user has the same rights as the author. If GeoVEs cannot be edited by the authoring

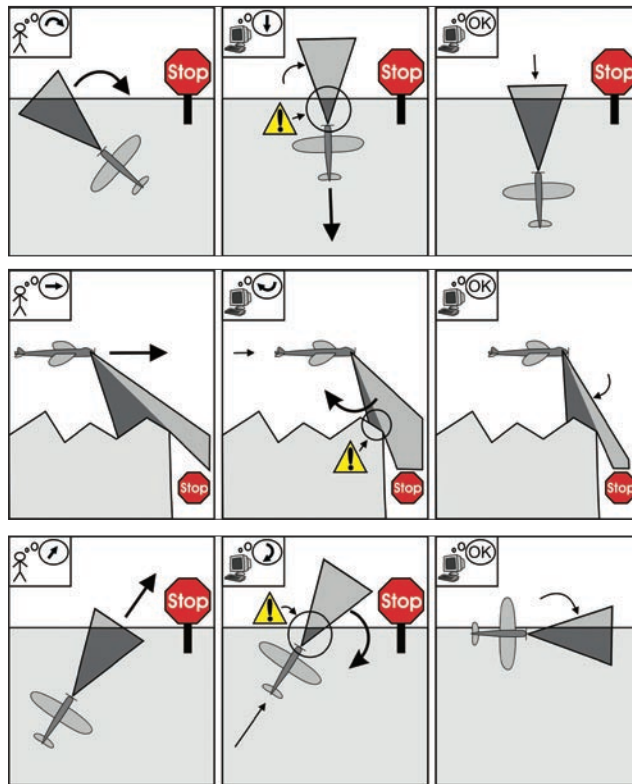


Figure 5. Example for constraints using orientation measurements. a) Due to the camera rotation, large parts of the view frustum do not contain defined contents. The strategy moves the camera back towards the inner part of the GeoVE. b) The camera approaches and stops close to the border of the GeoVE. The strategy then tilts down the view direction to increase the amount of visible inner parts. c) The camera is going to pass the border of the GeoVE. To prevent this, the strategy turns the camera right.

system, the usage rights and constraints apply and cannot be bypassed.

With redistribution constraints, authors of distributed GeoVEs are guaranteed copyright and license regulations to a certain degree. The effectiveness of these constraints also depends on the technical means used for their implementation, e.g., algorithms for encoding watermarks in digital data sets. Conceptually, these constraints systematically apply techniques of digital rights and encryption to geovisualization.

Distributed GeoVEs

The sample implementation of the underlying GeoVE concepts is built on top of the LandXplorer geovisualization system. GeoVEs have been used in various situations such as city planning projects, city information systems, and in planning radio networks. Based on this expe-

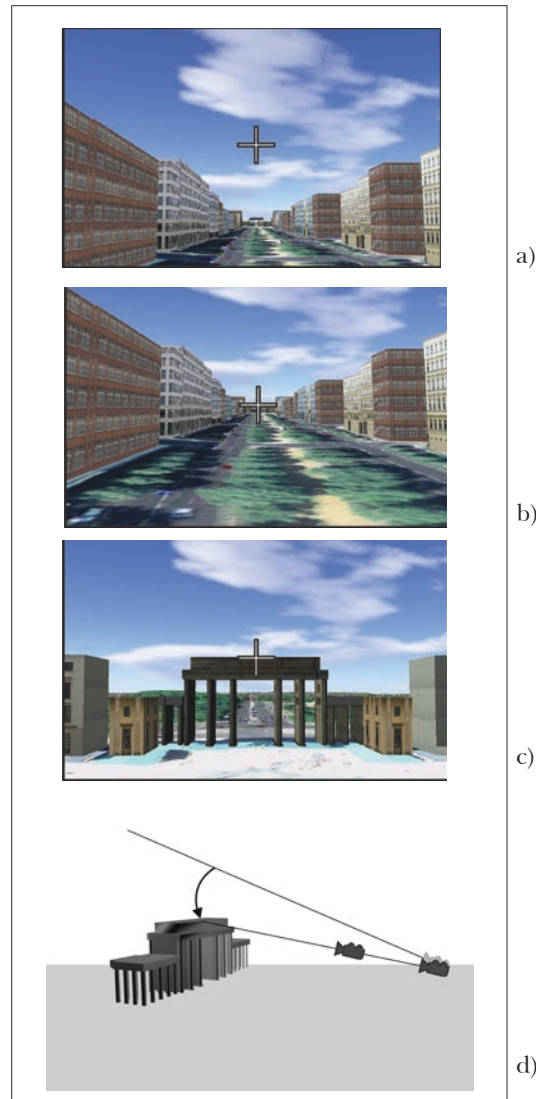


Figure 6. Examples of a strategy that prepares views for the focus navigation. a) The current view cannot be processed by the focus navigation because no focus point is defined—the viewplane center points towards the sky. b) To adjust the view, the system tilts down the view direction during a short animation phase. c) After the adjustment, the focus navigation as well as the zoom navigation are now able to work. d) Illustration of the adjustment process.

rience, three representative types of distributed GeoVEs can be distinguished:

- *Use-Only GeoVEs:* These environments apply most restrictive constraints to ensure that users do not alter the composition of the GeoVEs, and they ensure that GeoVEs are not redistributed, e.g., take a distributed 3D city models containing new planning where users can only explore a new construction project.



Figure 7. Example of the distance-texture constraint. The three images [top left, top right, and left] show the same terrain except that with decreasing distance to the terrain surface (left to right), a copyright texture blends in.

Figure 8 [below]. User interface of the interactive Berlin-3D application. Its implementation is based on the LandXplorer system and deploys constraints for both user guidance and DRM. The semi-transparent walls indicate the route of the underground railway system.



- *Personalized GeoVEs*: These allow users to insert personal geoinformation (e.g., scanned maps) and general-purpose information (e.g., comments), and to save the modified versions of the GeoVE. Most commonly personalization is achieved by inserting annotations, for example, objects such as points, lines, and polygons created by the user.
- *Customizable GeoVEs*: These environments define a number of explicitly “free slots” for user-specific graphics objects such as the number of terrain textures used to represent customer-specific thematic information.

Example Application

Constraints described in this paper have been applied in the case of a DVD software product (3D Geo 2004b) which contains a fully featured 3D city model (Figure 8). The constraints protected the geodata contained in the model from being captured using distance-textures as watermarks. They also prohibited true ortho views, and hence the systematic capture of HRSC aerial photography. They tended to avoid “disadvantageous views” (e.g., coming too close to the ground or coming too close to areas with lower data quality). Interestingly, but still to be studied systematically, most users did not realize the presence of constraints.

Structure constraints turned out to be excellent tools for adjusting the capabilities for the personalization of 3D city models. In a Berlin-3D application, the users can partially modify the GeoVE by adding and removing their own points of interest but they are not allowed to change the overall structure of the GeoVE.

Conclusions

Spatial, structure, and redistribution constraints address the two not necessarily linked needs of authors of interactive 3D GeoVEs, namely the protection and control of GeoVE contents based on an established DRM policy and to provide smart interaction control in the form of guided navigation. It was observed that constraints can be applied successfully to configure end-consumer geovisualization products such as, for example, interactive 3D city and mountain information systems. In these systems, DRM and usability are critical and tightly linked requirements.

Future work will look to improving the behavior and cooperation of spatial constraints. For 3D city models, numerous constraints taking advantage of the semantics of their components (e.g., buildings, streets, bridges) could be investigated to develop better guidance strategies. This research would benefit from implementing it on the basis of upcoming DRM standards.

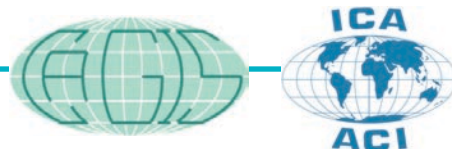
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